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FINAL REPORT

SEDIMENT QUALITY EVALUATION REPORT
GOWANUS CANAL AND BAY
ECOLOGICAL RESTORATION PROJECT

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EXECUTIVE SUMMARY

As part of the Gowanus Bay and Gowanus Canal Ecological Restoration Project, the USACE is assessing sediment quality within the Gowanus Canal. The Gowanus Canal proper is a highly developed urban area located in Brooklyn, New York. Residential communities such as Carroll Gardens and Red Hook border the canal. The canal is impacted by poor water quality, contaminated sediments containing a variety of inorganic and organic constituents, and a poor benthic community structure as the result of a century of heavy industrial use.

This report summarizes the findings of that data evaluation and provides "an assessment of known contaminants in relation to known (acceptable limits). The goal of this report is to provide the USACE with an understanding of the quality of sediment within the Gowanus Canal such that decisions on potential restoration and remedial approaches may be made.

The USACE collected sediment samples from 30 locations beginning from the head of the Gowanus Canal into Gowanus Bay. Samples were collected using a two-foot long 1-3/8 inch (ID) split spoon sampler. Samples were analyzed for volatile organics, semi-volatile organics, pesticides and PCBs, RCRA metals, mercury, and total petroleum hydrocarbons. Samples also received bacteriological analysis.

The process of evaluating the chemical and bacteriological data provided by USACE was approached in an iterative three-step fashion. The first step in the process was the comparison of the sediment sampling results to appropriate sediment quality benchmarks. If an organic compound or inorganic constituent at any given sampling location exceeded a benchmark (or if a benchmark was not available), then it was carried to the next step which was a comparison to the background loading of contaminants found within the New York Harbor. Readily available information was evaluated to identify concentrations of organic compounds and inorganic constituents that had been detected in the sediments of New York Harbor.

For organic compounds and inorganic constituents that exceeded both their respective sediment screening value and their regional background, a final step was applied to evaluate the relative

hazards of each sampling station. For each organic compound and inorganic constituent, a numerical rating between 1 and 5 (one being best, five being worst) was assigned in each of the categories of toxicity, bioaccumulation potential, persistence, and bioavailability. The rating was assigned based on professional judgment following a review of the literature regarding the chemical makeup of each analyte. Then, at each sampling location, the numerical ratings of the organic compounds and inorganic constituents that exceeded their benchmark and their background value (or for which there was no benchmark or background) were summed to get a total hazard rating. A sample-specific weighting factor based on the level of benchmark exceedance was also utilized.

The results of the sediment sampling conducted by the USACE indicated that a variety of organic and inorganic constituents are present throughout the Gowanus Canal and Gowanus Bay. As would be expected, concentrations of the various constituents were generally higher at locations that were further up the canal. This is where tidal flushing is at a minimum and where the greatest residence times for constituents that have been released into the canal would occur.

In general, the number of constituents that exceeded their respective sediment screening criteria increased the further upstream the samples were collected. However, there were some upstream locations that had relatively few exceedances. In the majority of the downstream locations, inorganic constituents dominated the exceedances. For example, the furthest downstream location had eleven constituents that exceeded benchmarks (or for which benchmarks were not available). Of those, ten were inorganic constituents. In the middle section of the Gowanus Canal, the exceedances were dominated by PAHs. Towards the end of the Gowanus Canal, the exceedances were equally distributed between the various classes of analytes.

The samples that were collected within the Gowanus Bay generally had low numbers of constituents that exceed both sediment screening benchmark values and average background numbers. The majority of those constituents are metals. Even within the bay, there are areas that have a number of organic constituents that exceed both sediment quality benchmarks and average background values, or that have constituents for which there is no background or benchmark. However, the Canal samples show a progressively larger number of constituents

that exceed both sediment quality benchmarks and the average background numbers than seen in the bay, and those increased in an upstream direction. The exception to this is at the very end of the Gowanus Canal where the actions of the Gowanus Flushing Tunnel, which was built in 1911 and reactivated in 1999 to increase water circulation at the end of the Canal, has resulted in higher sediment quality in comparison to areas of the Gowanus Canal that are just downstream.

USACE conducted bacteriological analysis on 25 of the collected samples. The bacteria that were identified in the sediment samples included bacterial specimens that are commonly found in the environment and do not have any affect on humans, as well as those that can be infectious upon coming in contact with humans. Several of the species are commonly found in human gastrointestinal tracts and are components of human waste and sewage.

The results of the hazard ranking confirmed the trends observed in the other data evaluation steps. That is the hazard values increase from downstream to upstream with the samples in the Gowanus Bay having the lowest values and the highest hazard values being location upstream in the Gowanus Canal. However, the highest value was actually in the middle section of the canal, while the next highest location was just upstream. In both instances, the hazard scores were driven by a large number of PAHs that were present at high concentrations.

In conclusion, the USACE sediment sampling characterized the sediments in the Gowanus Bay and Gowanus Canal as ranging from fair and consistent with the general health of New York Harbor sediments (in Gowanus Bay) to very poor (upper reaches of the Gowanus Canal). This information should be used to focus future sediment delineation, benthic habitat characterization or approaches for restoration and remediation.

1.0 INTRODUCTION

Under the Hudson-Raritan Estuary (HRE) Project, the U.S. Army Corps of Engineers (USACE), New York District (NYD), is currently performing an Ecological Restoration feasibility study focused on the Gowanus Canal, Gowanus Bay and surrounding upland. The HRE evaluation program includes all waters of the New York and New Jersey harbor, and tidally influenced portions of all rivers and streams that empty into and/or ecologically influence the harbors. The HRE Project has identified three spin-off sites, which are areas where separate studies are pursued as appropriate because those studies contribute to an understanding of the overall ecosystem. The Gowanus Canal and Gowanus Bay have been identified as a spin-off site under the HRE Project.

As part of the Gowanus Bay and Gowanus Canal Ecological Restoration feasibility study, the USACE is assessing sediment quality within the Gowanus Canal. The Gowanus Canal proper is a highly developed urban area located in Brooklyn, New York, which is bordered by residential communities such as Carroll Gardens and Red Hook. The canal is impacted by poor water quality, contaminated sediments containing a variety of inorganic and organic constituents, and a poor benthic community structure as the result of a century of heavy industrial use.

This report summarizes the findings of the evaluation of sediment and provides "an assessment of known contaminants in relation to known acceptable limits". The goal of this report is to provide an understanding of the quality of sediment within the Gowanus Canal such that decisions on potential restoration and remedial approaches may be made.

1.1 REPORT ORGANIZATION

This Sediment Evaluation Report begins with a review of the Gowanus Canal area and the general physical and environmental conditions of the waterbody (Section 2.0). Section 3.0 summarizes the sediment sample collection program implemented by the USACE and describes how the sediment data are to be evaluated. Section 4.0 discusses the general distribution of

contaminants throughout the Gowanus Canal and Gowanus Bay, based on the 2003 sampling conducted by the USACE.

Appendix A graphically presents the distribution of individual chemicals at each sampling location (Figures A-1 through A-46). Appendix B presents a comparison of the benchmarks, background concentrations and detected values for those constituents at each sampling location that exceeded both their benchmark and their average background concentration (Figures B-1 through B-22). Appendix C presents the hazard score calculation for each individual sampling location (Tables C-1 through C-25).

2.0 PROJECT OVERVIEW

This section presents a brief summary of the physical characteristics of the Gowanus Canal and describes the USACE program that collected the sediment data and how those data were evaluated in this report.

2.1   SITE DESCRIPTION

The Gowanus Canal and Gowanus Bay are located in Kings County (Brooklyn), New York and are part of the New York Harbor Estuary (see Figure 2-1). The elevation of the land surrounding the Gowanus Canal generally ranges from 0 to 30 feet above Mean Sea Level (MSL). Stormwater from the surrounding neighborhoods drains into the Gowanus Canal. There are 12 permitted combined sewer outfalls (CSOs) that discharge to the Gowanus Canal and an even larger number of unpermitted and illegal discharges.

Together, the Gowanus Canal and Gowanus Bay cover approximately 130 acres. The Gowanus Canal extends from Hamilton Avenue to Butler Street in Brooklyn (approximately two miles in length). The Gowanus Bay extends from Bay Ridge Channel to the beginning of the Gowanus Canal at Hamilton Avenue. The watershed feeding into the Gowanus Canal is approximately six square miles in area.

The Gowanus Canal was built to facilitate commercial shipping, barge traffic and other commercial users.   Originally built in 1881, the Gowanus Canal was constructed by digging out the Gowanus Creek. For much of its length, the Gowanus Canal is relatively narrow, with its banks stabilized by piers or bulkheads.

The Canal passes through a heavily urbanized section of Brooklyn that is bordered by residential communities such as Park Slope, Carroll Gardens, and Red Hook. Throughout its history, the Canal has provided commercial shipping access for a variety of industries, including oil refineries, machine shops, manufactured gas plants (MGP), chemical plants, soap makers and tanneries. The Canal is under severe environmental stress from a number of chemical releases

and spills as a result of the over 100 years of industrial use. Stormwater and numerous CSOs discharging into the Canal have resulted in the continual release of contaminants into the Canal. While the canal was constructed in 1881, it was not until 1987 that a sewage treatment plant (Red Hook Wastewater Treatment plant) was constructed in an effort to improve the area's sewage problem and limit the load of contaminants being discharged into the Canal.

The narrow width of the canal, coupled with its long reach from the bay, has limited the ability of tidal movement to flush contaminants from the system, resulting in a semi-stagnant body of water. In 1911, a water circulation system was constructed to bring water into the Canal from the New York Harbor to increase the movement of water within the canal (called the Gowanus Flushing Tunnel). The system operated until the mid-1960's at which time it ceased operation due to mechanical failure. The system was reactivated in April 1999 and continues to function to this day.

2.2   USACE SEDIMENT SAMPLING PROGRAM

The USACE collected sediment samples from the Gowanus Canal and Gowanus Bay in April and May 2003 as part of the Ecological Restoration feasibility study. The purpose of the study was to assess aquatic ecosystem needs and identify restoration opportunities, then select the best alternative for a future project. The objective of the sediment sampling program was to develop baseline information regarding sediment quality that would be used to identify issues of concern in the Gowanus Canal and the Gowanus Bay. The sampling was also intended to provide data regarding the geotechnical, chemical and bacteriological condition of the sediments within these waterbodies.

As shown on Figure 2-2, the USACE collected sediment samples from 30 locations beginning from the head of the Gowanus Canal to the Gowanus Bay. As noted in USACE (2003), samples were collected using two-foot long 1-3/8 inch (ID) split spoon samplers. Samples were generally collected to about 30 feet below (-30 feet) Mean Lower Low Water within the Gowanus Canal and 40 feet below (-40 feet) Mean Lower Low Water within the Gowanus Bay.

The sediments were analyzed for the following constituents:

- ➢ Volatile organics utilizing EPA SW-846 Method 8260;
- ➢ Semi-volatile organics utilizing EPA SW-846 Method 8270;
- ➢ Pesticides and PCBs utilizing EPA SW-846 Method 8081/8082;
- ➢ RCRA metals utilizing EPA SW-846 Methods 3051 and 6010B;
- ➢ Mercury utilizing EPA SW-846 7471B;
- ➢ Total petroleum hydrocarbons utilizing NJDEP Method OQA-QAM-025; and
- ➢ Bacteriological analysis.

It is noted that not every one of the above analytes were analyzed at every sampling location. A full description of sampling methodologies and approaches for all geotechnical, chemical and bacteriological sampling within the Gowanus Canal and Gowanus Bay can be found in USACE (2003).

2.3   PHYSICAL CHARACTERIZATION OF SEDIMENTS IN THE GOWANUS CANAL

As noted in USACE (2003), the bottom of the Gowanus Canal, with few exceptions, is covered by a soft, dark gray to black, highly plastic layer of clay. This clay unit typically had a decaying organic odor associated with it and weak petroleum-type sheens were noted in some samples. The clay layer was reported to be absent on the south side of the canal near 20th Street; within and near the 6th Street Basin; and near the Carroll Street Bridge. Beneath the clay layer, the deeper sediments were characterized as sands, silty sands, and poorly graded sands, often with traces of gravel. A general lithology of the canal is shown in Figure 2-3.

2.4   TECHNICAL APPROACH TO DATA EVALUATION

The evaluation of the chemical and bacteriological data provided by USACE was approached in an iterative three-step fashion. The objective of the evaluation was to characterize the sediment quality within the Gowanus Canal and Gowanus Bay and to provide the USACE with data to be used in planning for future remedial actions and/or restoration alternatives. The screening

process was conducted consistent with *Selecting Remediation Techniques for Contaminated Sediments* (U.S. Environmental Protection Agency [USEPA], 1993) and *Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (USEPA, 2001).

The first step in the process was the comparison of the sediment sampling results to appropriate sediment quality benchmarks, including those presented in the *New York State Department of Environmental Conservation Technical Guidance Manual for Screening Contaminated Sediments* (NYSDEC, 1993). That document published a series of criteria for non-polar organic compounds and metals that are to be used within the State of New York to identify areas of sediment contamination and as part of the preliminary assessment of the risks posed by the contamination to human health and the environment. If a benchmark was not available from the NYSDEC guidance manual for a constituent that was identified in the sampling program, then other benchmark sources were investigated. Those sources included NJDEP (1988), Environment Canada (1992), MacDonald (1994), Long *et al.* (1995), TNRCC (2001), and USEPA Region IV (2001).

If an organic compound or inorganic constituent at any given sampling location exceeded a benchmark (or if a benchmark was not available), then it was carried to the next step which was a comparison to the background loading of contaminants found within the New York Harbor. Readily available information was evaluated to identify concentrations of organic compounds and inorganic constituents that had been detected in the sediments of New York Harbor. Specific references for information regarding sediment quality within the New York Harbor area used in the evaluation of the Gowanus Canal sediment data included:

1. *Characterization of Pathogen Contamination in the NY-NJ Harbor Estuary*. M.D. Gastrich, et al., NJDEP (1990);
2. *Lurking on the Bottom: Heavy Metals in the Hudson-Raritan Estuary*. S.L. Clark. Environmental Defense Fund (1990);
3. *New York/New Jersey Harbor Estuary Program, Module 3.1: Toxics Characterization Report*. K.S. Squibb, J.M. O'Connor and T.J. Kneip; Institute of Environmental Medicine, New York University Medical Center (July 1991);
4. *Assessment of Pollutant Loadings in New York-New Jersey Harbor*. HydroQual Report for the Hudson River Foundation (1991);

5. *Sediment Toxicity and Concentrations of Trace Metals in Sediment and Pore Water in NY/NJ Harbor*. Battelle Ocean Sciences. Final report submitted to NYCDEP (June 18, 1992);
6. *Data Report for Task II of Study of PCB in New York/New Jersey Point Sources*. Battelle Ocean Sciences (January 1993);
7. *NY-NJ Harbor/Bight Estuary Program, CCMP Supporting Document: Pathogen Contamination*. M.D. Gastrich, NJDEP, in consultation with the Pathogen Work Group. (February 1995);
8. *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States (Volumes I, II & III)*, EPA 823-R-97-006 (March 1997);
9. *Sediment Quality of the NY/NJ Harbor System, An Investigation under the Regional Environmental Monitoring and Assessment Program (R-EMAP)*, USEPA, EPA/902-R-98-001 (March 1998);
10. NOAA National Status and Trends: Biological effects of Toxic Contamination in Sediments from Long Island Sound and Environs database. Douglas A. Wolf et al. NOAA (February 1999); and
11. *Health of the Harbor, The First Comprehensive Look at the State of the NY/NJ Harbor Estuary*, Hudson River Foundation (2004).

A final step was used to evaluate the relative hazards of each sampling station. For each organic compound and inorganic constituent that exceeded both their respective sediment screening value and their regional background, a numerical rating between 1 and 5 (one being best, five being worst) was assigned in each of the categories of toxicity, bioaccumulation potential, persistence, and bioavailability. The rating was assigned based on professional judgment following a review of the literature regarding the chemical makeup of each analyte. Then, at each sampling location, the numerical ratings of the organic compounds and inorganic constituents that exceeded their benchmark and their background value (or for which there was no benchmark or background) were summed to get a total hazard rating. A sample specific weighting factor, based on the level of benchmark exceedance, was applied to the sum. The weighting factor increased with the margin by which the benchmark was exceeded, so that a constituent that slightly exceeded the benchmark was not treated the same as the constituents that significantly exceeded the benchmark (*i.e.* 1x if concentration is equivalent to the benchmark, 2x if the concentration is one order of magnitude greater than the benchmark, 3x if the concentration was 2 orders of magnitude greater, and 4x if the concentration was 3 orders of magnitude greater).

3.0 DISTRIBUTION AND CHARACTERIZATION OF CONSTITUENTS

The results of the sediment sampling conducted by the USACE indicated that a variety of organic and inorganic constituents are present throughout the Gowanus Canal and Gowanus Bay. Concentrations of the various constituents were generally higher at locations that were further up the canal than those in the lower end and in Gowanus Bay. The upper section of the canal is where tidal flushing is at a minimum and where the greatest residence times for constituents that have been released into the canal would occur. However, the complete upstream section of the canal (sample location GC-03-30) did show some decrease in the presence of the various constituents over the other upstream sections of the canal. The reason for that trend is the action of the flushing tunnel that has restored mixing to the water column and acts to remove some of the constituents released into the canal which otherwise would settle to the bottom.

The following sections discuss the identification and distribution of the various classes of constituents that were identified. Appendix A graphically presents the distribution of individual chemicals at each sampling location (Figures A-1 through A-46).

3.1 TOTAL PETROLEUM HYDROCARBONS

Concentrations of Total Petroleum Hydrocarbons (TPHC) were identified at four locations (GC-03-07, GC-03-26, GC-03-27 and GC-03-08).

3.1.1 Ecotoxicological Characterization of TPHC

USEPA defines TPHC as "a measure of the concentration or mass of petroleum hydrocarbon constituents present in a given amount of air, soil, or water." Petroleum is a mixture of hydrocarbons that can be classified into two broad groups, aliphatic hydrocarbons that can be further divided into alkanes, alkenes, and cycloalkanes, and the aromatic hydrocarbons. The percentage of each group present varies with both the source of crude oil and the refined product.

The compounds within these two chemical groups exhibit a range of toxicity, with some being extremely toxic, while others are relatively benign. In general, the toxicity of hydrocarbons is related to their chemical structure and their affinity for water, with more soluble compounds being relatively less toxic. While this is a general relationship and can be affected by chemical structures, compounds that are more soluble in water are less soluble in fat. As the solubility in fat or lipids increases, solubility in water decreases and the ability of the hydrocarbon to cross the cell membrane and produce biological damage increases. This relationship also suggests that as lipid solubility increases, the potential for the chemical to be passed up through the food chain increases (from an original food source to a lower level predator; then to higher levels of predators).

3.1.2   Distribution of TPHC

TPHC results were the one class of constituent that did not follow the trend of having the highest concentrations in the furthest upstream sampling locations. Sample station 28 had the lowest concentration with 1,000 mg/kg, whereas the next downstream location (station 27) jumped to over 5,000 mg/kg. The next downstream location (station 26) had 1,728 mg/kg and the furthest downstream station that was collected (station 7) had a concentration of 3,794 mg/kg. This distribution supports the belief that the flushing tunnel is having a positive effect on sediment quality by increasing water mixing that prompts environmental degradation of surficial sediment contamination and controls the deposition of water borne constituents onto the sediment. Figure 3-1 depicts the distribution of TPHC concentrations at the four sampling locations.

3.2   VOLATILE ORGANIC COMPOUNDS

The USACE sampling identified fifteen volatile organic compounds (VOCs) throughout the Gowanus Canal and Gowanus Bay system. Those compounds included acetone, benzene, 2-butanone, carbon disulfide, chlorobenzene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, cis-1, 2-dichloroethene, ethylbenzene, 2-hexanone, methylene chloride, styrene, toluene, m + p xylenes, and o-xylene.

3.2.1   Ecotoxicological Characterization of VOCs

VOCs are a class of organic constituents that are classified by having a vapor pressure of greater than 0.1 mm Hg. They tend to rapidly pass into a vapor state from a liquid state. Many of the VOCs that were identified in the sediments of Gowanus Bay and Gowanus Canal are breakdown products from petroleum. Some of the VOC constituents are breakdown/degradation products of other VOCs.

In general, VOCs are not considered to be a significant long-term hazard to ecological resources in sediments. They are non bioaccumulative and because of their rapid degradation rates, they are not persistent in the environment. In aquatic settings, many of the toxicological thresholds for VOCs are relatively high in comparison to other organic constituents.

3.2.2   Distribution of VOCs

Figure 3-2 shows the distribution of VOC concentrations on a total VOC per sample basis. The most frequently identified VOCs included acetone, methylene chloride, and 2-butanone, chemicals that are frequently detected in environmental samples due to their standard use as reagents in analytical processes.

The highest concentrations were in upstream areas, with the highest concentrations being found at Station 24, Station 25, and Station 26. That is the stretch of the canal between the 1st Street Extension and the 4th Street Basin. The constituents that were primarily noted in this included VOCs associated with petroleum degradation (benzene, toluene, ethylbenzene, and xylene). It is interesting to note that the distribution is not strictly linear, with some areas of total VOC concentrations upstream that are lower than those samples collected from the Bay. It is also noted that the two most upstream stations where VOC samples were collected (Station 27 and Station 28) both have total VOC concentrations that are less than the most downstream location. Again, this supports the belief that the flushing tunnel is having a positive affect on the quality of sediment in the most upstream segments of the Gowanus Canal.

3.3   SEMI-VOLATILE ORGANIC COMPOUNDS

A total of 24 semi-volatile organic compounds (SVOCs) were detected in the sediments of Gowanus Canal and Gowanus Bay. Those SVOCs included: acenaphthene, acenaphthylene, anthracene, benzo(a)pyrene, benzo(a)anthracene,   benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene,   bis(2-ethylhexyl)phthalate,   chrysene,   dibenz(a,h)anthrancene, dibenzofuran, diethylphthalate, di-n-butylphthalate, di-n-octylphthalate, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene,   2-methylnaphthalene,   naphthalene,   n-nitrosodiphenylamine, phenanthrene, phenol, and pyrene.

3.3.1   Ecotoxicological Characterization of SVOCs

The majority of these constituents are in a family of chemicals known as polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of naturally occurring chemicals that are ubiquitous in nature, produced by forest fires, microbial synthesis, and a number of anthropogenic activities such as burning of garbage and other organic materials, though the majority of the presence of PAHs in the environment is due to anthropogenic releases (ATSDR, 1995). They are also commercially manufactured for research purposes as well as for medicines, dyes, or as intermediates in other manufacturing processes on a more limited basis. There are more than 100 different PAHs, but they generally occur as complex mixtures rather than as individual compounds (ATSDR, 1995).

In general, PAHs are not easily dissolved in water. They are present in air as vapors or stuck to the surfaces of small solid particles. In soils and sediments they are most likely to stick tightly to particles. Sediment bound PAHs biodegrade slowly, while PAHs in many organisms are rapidly metabolized and excreted (ATSDR, 1995). Despite their high lipid solubility, most PAHs show little tendency to biomagnify in food chains, probably because they are rapidly metabolized in most biota (Eisler, 2000a). PAHs are teratogenic, mutagenic, and carcinogenic, with the higher molecular weight compounds being less toxic than lighter compounds (Eisler, 2000a).

Sediment concentrations associated with the potential for impacts to aquatic invertebrates and fish have been established for many individual PAHs. In addition, values have been derived for total PAHs, as well as for low molecular weight and high molecular weight groups of PAHs. Based on the available data, No Observed Adverse Effects Level (NOAELs) range from 0.25 mg/kg (MacDonald, 1994) to 0.55 mg/kg (Long et al., 1995) for low molecular weight PAHs. NOAELs for high molecular weight PAHs are higher, ranging from 0.87 mg/kg (MacDonald, 1994) to 1.7 mg/kg (Long et al., 1995). Sediment quality guidelines for total PAHs range from 2.9 mg/kg (MacDonald, 1994) to 44.8 mg/kg (Long et al., 1995).

3.3.2   Distribution of SVOCs

Figure 3-3 shows that the SVOCs identified in the Gowanus Canal and Gowanus Bay are concentrated in the upstream sections of the Canal. The full range of low, middle and high molecular weight PAHs were identified in the samples. The distribution of those constituents varied with location, with low-molecular weight PAHs such as acenaphthylene, acenapthene, and fluorene having the highest concentrations at the downstream locations. The higher molecular weight PAHs such as benzo(a)anthracene and chrysene had the higher concentrations in the upstream locations. This phenomenon could possibly be related to the more stagnant water conditions in the upstream locations and the resulting lack of degradation of the PAHs. The PAHs were found in the tens of thousands of mg/kg.

While significant concentrations can be found in the downstream sections of the canal and in the bay, the concentrations found in the upper sections are higher by four orders of magnitude. The highest concentrations of total SVOCs were found in the stretch of the Gowanus Canal between the 6th Street Turning Basin and the 4th Street Basin. Most likely as a result of the actions of the flushing tunnel, there is a reduction in total SVOC concentrations in the most upstream section of the Canal in comparison to the segment between the 6th Street Turning Basin and the 4th Street Basin.

3.4   PESTICIDES/HERBICIDES

Five pesticides were detected in the sediments of the Gowanus Canal and Gowanus Bay. Those constituents included beta-BHC, dieldrin, 4,4'-DDT, 4,4'-DDE, and 4,4'-DDD.

3.4.1   Ecotoxicological Characterization of Pesticides/Herbicides

BHC, a commercial mixture of isomers of 1,2,3,4,5,6-hexachlorocyclohexane, is used as an insecticide and therapeutic scabicide in humans and animals (Merck, 1983). It is also used as an insecticide with a variety of fruit and vegetable crops and as a seed treatment, and employed as a topical treatment for head and body lice and scabies (ATSDR, 2003a). Primary removal processes for the isomers are via wet or dry deposition. Because of its water solubility, BHC has a tendency to dissolve and persist in the water column when released to water systems. It may also undergo adsorption or desorption processes with sediments and other materials in the water (ATSDR, 2003a). Biodegradation is the primary degradative process for BHC, while photolysis and hydrolysis are less significant (ATSDR, 2003a).

Dieldrin was once used extensively for the control of pests in the corn and citrus industries. It has also been utilized in timber preservation and as a termite control for plastic and rubber coatings of electrical and communications cables and for plywood and other boards (Sax and Lewis, 1987). The use of dieldrin as a pesticide has significantly decreased, however, due to the availability of more practical alternatives and the increased resistance of insects to the chemical (USEPA, 1980a). The uses of dieldrin were canceled voluntarily, or by the USEPA by 1989 (USEPA, 1990).

Dieldrin is persistent in the environment due to its resistance to transformation and degradation processes (ATSDR, 1991). In the atmosphere, dieldrin may be transported great distances and is generally removed via wet or dry deposition (Baldwin et al., 1977).

DDT (1,1,-trichloro-2,2-bis-(p-chlorophenyl) ethane) was one of the world's most widely used agricultural insecticides, until it was banned in the U.S. in 1973 (Gillis et al., 1995). It was also

used extensively for the control of malaria, typhus, and other insect-transmitted diseases. DDE (1,1-dichloro-2,2-bis-(p-chlorophenyl) ethylene), and DDD (1,1-dichloro-2,2-bis-(p-chlorophenyl) ethane) are degradation products of DDT and contaminants of technical grade DDT. DDD has also been used as a pesticide (ATSDR, 2002c). DDE has no commercial use (ATSDR, 2002c).

Releases of DDT to the atmosphere, surface water, and terrestrial environs occurred during agricultural and vector control applications. DDT and its metabolites are virtually ubiquitous and are continually being transformed and redistributed in the environment (ATSDR, 2002c). In addition, DDT, DDD and DDE are very persistent and tend to accumulate in biotic as well as abiotic media (ATSDR, 2002c).

3.4.2 Distribution of Pesticides/Herbicides

Positive detections of the five pesticides were made at five sampling stations (GC-03-2, GC-03-7, GC-03-27, GC-03-28, GC-03-29, and GC-03-30). The three most upstream sampling stations (Station 28, Station 29, and Station 30) had the highest concentrations of pesticides, with Station 28 having the greatest total concentration of all pesticides of approximately 300 ug/kg. The distribution of the pesticides varied depending upon location. Four pesticides (beta-BHC, 4,4'-DDE, dieldrin, and 4,4'-DDD) were found at the most downstream location, while only one pesticide (4,4'-DDD) was found at Station 27. Beta-BHC was only found in the downstream locations, while 4,4'-DDT was only found in the upstream locations. The only constituent found at all locations was 4,4'-DDD. The highest identified pesticide concentration was 150 ug/kg of 4,4'-DDD at Station 28.

3.5 POLYCHLORINATED BIPHENYLS (PCBs)

USACE analyzed sediments for the presence of polychlorinated biphenyls (PCBs).

3.5.1   Ecotoxicological Characterization of PCBs

Polychlorinated biphenyls (PCBs) are a family of man-made chemicals consisting of 209 individual compounds with varying toxicity (ATSDR, 2000c). Aroclor is the trade name for PCBs made by Monsanto. Common Aroclors include Aroclor 1242, 1248, 1254, and 1260. Because of their insulating and nonflammable properties, PCBs were widely used in industrial applications such as coolants and lubricants in transformers, capacitors, and electrical equipment. The U.S. stopped manufacturing PCBs in 1977 due to evidence that they are highly persistent and can accumulate in the environment. PCBs are therefore no longer commercially available (ATSDR, 2000c).

PCBs are no longer produced in the U.S. Current environmental concentrations are therefore the result of past disposal practices or the (re)cycling of PCBs previously introduced in the environment. The low water solubility and high K_{ow} indicate that PCBs will have a strong tendency to adsorb to soil and sediment particles. They are expected to have half-lives spanning years. Adsorption is further enhanced by the presence of organic matter, clay or microparticles onto which PCBs can partition. As a result, soil leaching is expected to be greatest in soils with low organic carbon levels. Adsorption and leaching potentials will also depend in part on the level of chlorination: the more chlorinated a PCB, the more it adsorbs and the less it leaches.

PCBs partition significantly from water into aquatic organisms, including fish. Measured bioconcentration factors (BCFs) in aquatic animals range from 26,000 to 660,000, indicating that these compounds have a high affinity for lipids. The bioaccumulation potential of PCBs is also expected to increase with higher chlorine substitution and lower water solubility. However, for the hepta- and octachlorophenyls, lower bioaccumulation values have been reported than for the hexachlorophenyls. Several reasons have been suggested for this phenomenon, including: less favorable steric effects, higher elimination rates, and higher binding to organic matter, which decreases bioavailability from water. Finally, PCBs have been shown to have the ability to biomagnify. This phenomenon has been observed both in aquatic and terrestrial food chains.

3.5.2   Distribution of PCBs

PCBs were found at five sampling stations (Station GC-03-4, GC-03-5, GC-03-28, GC-03-29, and GC-03-30, though at relatively low concentrations (0.26 mg/kg to 1.9 mg/kg). Aroclor 1260 was the only Aroclor that was detected.   The highest detections were at the upstream locations (Station 28, Station 29, and Station 30).

3.6   METALS

Thirteen metals were identified in the sediments of the Gowanus Canal and Gowanus Bay. Those metals included antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc.

3.6.1   Ecotoxicological Characterization of Metals

Antimony (Sb) is a naturally occurring metalloid element (displaying both metallic and nonmetallic properties) and exists in valence states III and V (Budavari, 1989; ATSDR, 1992). Metallic Sb and a few trivalent Sb compounds are the main forms for exposure and toxicity (ATSDR, 1992). Sb is used in metallurgical processes, paints and enamels, various textiles, rubber, and fire retardation (Sb trioxide). Some antimonials such as potassium antimony tartrate have been used medicinally as parasiticides (Beliles, 1979). Limited data are available regarding the toxicity of Sb in sediments. Data available for Sb from Long and Morgan (1991) are from only two marine systems, San Francisco Bay and Puget Sound.   Based on these data, concentrations of 2 mg/kg may be associated with mortality to benthic invertebrates, and disrupt or alter benthic communities. The AET (Apparent Effects Threshold) values for Puget Sound ranged from 3.2 mg/kg based on benthic community composition to 200 mg/kg based on a *Rhepoxynius abronius* amphipod bioassay.

Arsenic (As) is used primarily for wood preservation. It is also used in the production of herbicides, insecticides, algicides, and growth stimulants for animals and plants. In addition, As

may be used in industries that produce glass, nonferrous alloys, and electronic devices (ATSDR, 2000a). As occurs naturally in soils, sediments, aquifers, and surface water bodies.

Limited data exist on the toxicity of sediment-bound As. In general, concentrations above 37 mg/kg are at least moderately toxic to most species (MacDonald, 1994). Exposure to concentrations of As in sediment as low as 8.3 mg/kg caused mortality (51.7%) in juvenile *G. japonica* during a 10-day bioassay (Anderson et al., 1988). A median tolerant level of 5.1 mg/kg was determined for mummichog exposed to concentrations of 91.8 mg/kg in an acute 48-hr bioassay (Tsai et al., 1979). Sediment quality guidelines derived for As range from 7.24 mg/kg to 93 mg/kg. These values were based on concentrations reported to cause acute mortality to benthic invertebrates, and to disrupt or alter benthic communities.

Beryllium (Be) is a hard, grayish element that does not naturally occur in its elemental state. The element does occur as a chemical component of certain rocks, soil, and volcanic dust, and Be is present in a variety of compounds. Most Be ore is converted into alloys used in making electrical and electronic parts or as construction materials for machinery and molds for plastics (ATSDR, 2002a). Pure Be metal has applications in nuclear weapons and reactors, aircraft and space vehicle structures and instruments, X-ray machines, and mirrors. Be is naturally emitted to the atmosphere by windblown dusts and volcanic particles (USEPA, 1987a). The major emission source to the environment is the combustion of coal and fuel oil. Other anthropogenic processes, such as ore processing, metal fabrication, Be oxide production and use, and municipal waste combustion, release small amounts of Be as well (Cleverly et al., 1989; USEPA, 1987a; Fishbein, 1981). Be naturally enters waterways through the weathering of rocks and soils (USEPA, 1980b).

Cadmium (Cd) is used primarily as an electrode component of Ni-Cd batteries and for metal plating (ATSDR, 1999a). In addition, Cd often serves as a pigment in plastics and paints, and may also be used in Cd-bearing alloys and solders (USEPA, 1987b; ATSDR, 1999a). Cd occurs naturally in soils, sediments, aquifers, and surface water bodies.

In general, cadmium toxicity has been investigated to a greater degree than many metals. A 96-hr sediment LC_{50} of 37.9 mg/kg was derived for the copepod *A. tenuiremis* (Green et al., 1993). Reported LC_{50} values for the amphipod *R. abronius* in 10-day sediment bioassays range from 6.9 mg/kg (Swartz et al., 1985) to 11.5 mg/kg (Robinson et al., 1988). Similarly, Long et al. (1990) observed more than 50% mortality in adult *R. abronius* in a 10-day solid phase sediment toxicity test using metal contaminated sediments that contained cadmium at concentrations up to 8.33 mg/kg. Tay et al. (1990) observed 52% mortality in juvenile polychaetes (*Nereis spp.*) exposed to 0.2 mg/kg cadmium in a 20-day bioassay.

Chromium (Cr) and Cr complexes are used mainly to produce stainless steels, cast iron and nonferrous alloys, and other materials designed for heat or corrosion resistance. Cr complexes are also used as components of chrome and chrome-bearing magnetite products. Cr^{+3} is widely used in leather tanning, while Cr^{+6} is used in metal finishing and wood preservation. In addition, both Cr^{+3} and Cr^{+6} may be used in the production and application of pigments (ATSDR, 2000b). Cr occurs naturally in soils, sediments, aquifers, and surface water bodies.

Effects due to exposure to sediment-bound Cr occur over a wide range of concentrations. Most adverse effects are associated with Cr^{+6}. Available sediment quality guidelines based on concentrations reported to result in adverse impacts to benthic species ranged from a predicted no effect level of 33 mg/kg to a minimal effect level of 370 mg/kg. Concentrations of 37 mg/kg or less have been associated with exoskeletal lesions in crabs (*Cancer irroratus*) and lobster (*Homarus americanus*) (Pearce, 1972). Tsai et al. (1979) found that sediment concentrations between 335 and 1,646 mg/kg elicited toxic effects in mummichog.

Copper (Cu) is used for many applications, including: plumbing, roofing and building construction; chemical and pharmaceutical machinery, corrosion-resistant piping, catalyst, anti-fouling paint, and many others. Because of its high electrical and thermal conductivity, Cu is widely used in the manufacture of electrical equipment. In addition, common Cu salts, such as sulfate, carbonate, cyanide, oxide, and sulfide are used as fungicides, components of ceramics and pyrotechnics, for electroplating, and for numerous other industrial applications (ACGIH, 1986; Sax and Lewis, 1987). The largest anthropogenic releases of copper to the environment

result from mining operations, agriculture, solid waste, and sludge from sewage treatment plants. Natural discharges to air and water, such as windblown dust and volcanic eruptions, may be significant (ATSDR, 2002b).

Several researchers have demonstrated that exposure to relatively high concentrations of sediment-bound copper are lethal to a variety of organisms. Low richness of benthic species in sediments has been associated with copper concentrations ranging between 15 and 18 mg/kg (Gilbert et al., 1976). Maleug et al (1984) found significantly increased mortality of benthic species exposed to metal-contaminated sediments to be most correlated with sediment copper concentrations above 600 mg/kg. Similarly, Maleug et al. (1984) evaluated toxicity of sediments from the Keweenaw Waterway, MI to daphnids and concluded that observed mortality (96.7 to 100% at four locations) was likely due to the presence of copper at concentrations ranging from 480 to 930 mg/kg.

Lead (Pb) is used mostly in the production of storage batteries. Lead complexes are also widely used as gasoline additives and in ammunition. To a lesser degree, lead complexes are used in production processes of metal products such as solder, pipes, cable coverings, traps, and other extruded products (ATSDR, 1999b). Additionally, lead occurs naturally in soils, sediments, aquifers, and surface water bodies. Little information exists on sediment effects of Pb. Tay et al (1990) observed 61.7% mortality among adult *R. abronius* exposed to sediment Pb concentrations of 229 mg/kg in a 10-day bioassay. Similarly, Long et al. (1990) observed less than 50% survival in adult *R. abronius* exposed to Pb ranging from 20 to 227 mg/kg during a 10-day solid phase sediment toxicity test. In contrast, Eisler (2000b) observed only 78% mortality in populations of *R. abronius* exposed to 613 mg/kg lead during a 10-day bioassay, emphasizing the influence of site-specific factors on the bioavailability of sediment-bound Pb.

Mercury (Hg) and mercury compounds are used extensively in electrical and electronic applications, chlorine and caustic soda manufacture, and as components of measuring and control instruments, dental equipment, and paints (Reese, 1991). Mercury is a component of consumer products such as thermometers, batteries, radios, cameras, smoke alarms, watches, soaps, and lubrication oils (ATSDR, 1999c). Additionally, mercury occurs naturally in soils,

sediments, aquifers, and surface water bodies. In the atmosphere, elemental mercury is the most common form and the most likely to be transported the greatest distances (ATSDR, 1999c). Sediments may act as significant repositories for inorganic mercury since it is not readily desorbed from particulates. Leaching from soils is likely to be an insignificant process. Surface runoff, however, may provide an important mechanism for the transport of mercury from soils to water (Meili, 1991).

Greater than 50% mortality was reported in *R. abronius* exposed to sediments with Hg ranging from 0.23 to 8.33 mg/kg (Long et al., 1990). Similarly, Swartz et al. (1988) reported an LC_{50} of 13.1 mg/kg for *R. abronius* in a 10-day bioassay. In contrast, sediments containing a mixture of contaminants including Hg ranging from 2.71 to 34.89 mg/kg were not toxic to the polychaete *N. virens* or grass shrimp (Rubinstein et al., 1983). Hg levels of 0.1 to 0.2 mg/kg have been associated with low benthos species richness in Massachusetts Bay (Gilbert et al., 1976). Chapman et al. (1987) observed increased avoidance during a 10-day bioassay with amphipods exposed to San Francisco Bay sediments containing 0.57 mg/kg Hg. Tsai *et al.* (1979) observed toxic effects to mummichog at sediment concentrations ranging from 0.4 to 1.6 mg/kg.

Nickel (Ni) is a naturally occurring element that may exist in various mineral forms. It forms 0.008% of the earth's crust (NAS, 1980). Soil and sediment are the primary receptacles for nickel, but mobilization may occur depending on physico-chemical characteristics of the soil (ATSDR, 2003b; USAF, 1990). Nickel is used in a wide variety of applications including metallurgical processes and electrical components, such as batteries (ATSDR, 2003b; USAF, 1990).

Long et al. (1995) derived an ER-L (Effects Range-Low) of 20.9 mg/kg (dry weight), and Environment Canada (1994) derived a TEL (Threshold Effect Level) of 15.9 mg/kg for Ni in sediment. Chapman *et al*. (1987) observed 37% avoidance during a 10-day bioassay exposing adult amphipods to San Francisco Bay sediments with 94 mg/kg Ni. Levels between 41 and 173 mg/kg increased mortality in the amphipod *R. abronius* (Long et al., 1990). Tsai et al. (1979) observed toxicity to mummichog at sediment concentrations of Ni between 70 and 97 mg/kg.

Industries involved with the manufacture of photographic materials consume the largest portion of all silver (Ag) metals and compounds produced. Ag is also utilized in the production of electrical and electronic products such as electrical contacts, silver paints, and batteries. To a lesser degree, Ag may also serve as a component of bearings, solders, electroplated ware, jewelry, mirrors, dental and medical supplies, and chemical products. Additionally, Ag occurs naturally in soils, sediments, aquifers, and surface water bodies (ATSDR, 1990).

In surface waters and soils, the transport and partitioning of Ag depends primarily on the specific compound. In water, Ag complexes may form ions, become adsorbed to suspended particulates, or may be adsorbed by or onto aquatic biota (Boyle, 1968). Sorption is the dominant process of partitioning of Ag to sediments (Callahan et al., 1979). This process, however, is influenced by pH and oxidation-reduction conditions (Anderson et al., 1973). The same processes, with the addition of organic matter, are the primary variables affecting the partitioning of Ag in soils (Boyle, 1968). Biotransformation of Ag complexes in soils is not a significant process (Domsch, 1984).

Limited information is available regarding the sediment- or tissue-associated effects of Ag. Available sediment quality guidelines range from 0.5 to 6.1, based on Ag concentrations reported to cause acute mortality to benthic invertebrates, and disrupt or alter benthic communities. Chapman et al. (1987a) observed 37% avoidance during a 10-day bioassay exposing adult amphipods to San Francisco Bay sediments with an Ag concentration of 8.1 mg/kg.

Selenium occurs naturally at average concentrations of 33 ppm. The oxidation state and solubility of selenium are controlled by the oxidation-reduction regime and the environmental pH. In well-drained mineral soils that are pH neutral, selenites exist exclusively, which are rapidly and nearly completely fixed by iron oxides and other oxides; these compounds are only slightly bioavailable. In alkaline and well-oxidized soils, selenates exists which are easily soluble and readily bioavailable to plants. In acid-gley soils and soils with high organic matter content, selenides and selenium sulfides dominate which are only slightly mobile and are not bioavailable. Biological methylation is common. In sediments, selenium is associated with the clay fraction and occurs at concentrations less than one ppm. The presence of phosphate and

sulfate reduce selenium adsorption. Sources of selenium include the combustion of coal (Pendias and Pendias, 1992).

Bioavailability of selenium is controlled by the oxidation state (Ingersoll *et al.*, 1997). The bioaccumulation of selenium usually occurs through uptake of water rather than from the diet as the diet threshold is considerably lower. Mortality usually occurs for aquatic organisms at concentrations of selenium of 6.5 mg/kg where organisms can tolerate concentrations in sediment of 30 mg/kg. Based on this, a dietary threshold of 3 mg/kg is recommended. Selenium body burdens increase two to six times through the food chain. Water concentrations of 2 to 16 μg/L yield BCFs ranging from 500 to 35,000 (Beyer *et al.*, 1996)

Thallium concentrations in US soils range between 0.02 and 2.8 ppm. Thallium occurs in three oxidation states – Tl^+, Tl^{2+}, and Tl^{3+}. It has an affinity to micaceous minerals and is fixed *in situ* by clays and gels of manganese and iron oxides. Thallium sorbs to organic matter under reducing conditions but when weathered, it is readily mobilized and transported with alkaline metals (Pendias and Pendias, 1992). Aquatic organisms readily take up thallium; bioaccumulation may occur. BCFs for some aquatic organisms are 11 (mussels), 150,000 (freshwater invertebrates), and 100,000 (freshwater fish) (USEPA, 1985).

Zinc (Zn) is a metal that has many uses in industry. It can be found in pure form or mixed with other metals to form alloys such as brass. It can also be found combined with other chemicals, such as chlorine (zinc chloride). Zn compounds are found naturally in the air, soil, and water, and are present in all foods. Zn is an essential element needed by the body in low doses. The primary sources of Zn in the environment are related to metallurgical wastes from smelter and refining operations.

Available sediment quality guidelines range from 68 mg/kg to 960 mg/kg, based on concentrations reported to cause acute mortality to benthic invertebrates, and disrupt or alter benthic communities. In general, biological effects have not been associated with zinc concentrations in sediments less than about 50 mg/kg (Long et al., 1990). However, behavioral effects have been observed at slightly higher concentrations. For example, Oakden et al. (1984)

reported increased avoidance (67.2%) in the amphipod *R. abronius* exposed to concentrations of 51 mg/kg during a 72-hour bioassay. In contrast, Chapman et al. (1987a) observed 37% avoidance during a 10-day bioassay in which adult amphipods were exposed to San Francisco Bay sediments with 321 mg/kg zinc.

3.6.2   Distribution of Metals

Overall, the distribution of metals in Gowanus Canal and Gowanus Bay appeared to follow the trend of having the highest concentrations in the upstream samples. However, a closer examination of the distribution of the concentrations (Figure 3-6) indicates that except for four outliers that are found at Station 23 (head of the 4th Street Basin), and Station 27, Station 28 and Station 29 (between Carroll Street and the end of the Canal), the concentrations of total metals in the upstream sections are generally less than the downstream section of Gowanus Bay. However, the four outliers are significantly higher than the other upstream sample locations (in some instances they are 3 orders of magnitude higher). Positive detections were made of every RCRA metal (though not at every location). Chromium, copper and lead appear to be the metals that generally drove the elevated concentrations at the outlier locations and had the highest concentrations of any of the metals throughout the sampling locations.

4.0 EVALUATION OF CHEMICAL RESULTS

As outlined in Section 2.0, the chemical data were compared to two sets of values as a means of determining a basic understanding of the potential that constituents of concern in the sediment may have adversely impacted ecological receptors within the Gowanus Canal and Gowanus Bay aquatic ecosystem. The comparison of the USACE sampling results to these two sets of numbers, sediment quality benchmarks and background concentrations, was part of the iterative evaluation program that allowed for a focused examination of those sediment sampling locations that warranted further investigation or remedial evaluations. The following sections outline the results of the comparisons to the sediment quality benchmarks and the background concentrations. Appendix B presents a comparison of the benchmarks, background concentrations and detected values for those constituents at each sampling location that exceeded both their benchmark and their average background concentration (Figures B-1 through B-22).

4.1 COMPARISON OF SAMPLING RESULTS TO SEDIMENT QUALITY BENCHMARKS

The use of sediment quality criteria is a standard approach to evaluating the potential for constituents of concern that are found in sediments to impact ecological receptors (USEPA, 1992 and USEPA, 1994). Sediments are defined as the collection of mineral and organic particles that are found at the bottom of lakes, ponds, rivers, streams, bays, estuaries, and oceans. They are critical components of the aquatic ecosystems in that they provide habitat for benthic invertebrate organisms (those invertebrate organisms that fill the bottom of the food chain for higher level benthic and pelagic organisms) and many juvenile forms of pelagic species. The presence of contaminants in sediments may directly impact benthic organisms, or they may serve as a source of contaminants that are slowly released into the water column. Contaminants in sediments have been associated with restrictions on fish and wildlife consumption, degradation of fish and wildlife populations, fish tumors and other deformities, degradation of benthos, eutrophication of water bodies, and degradation of aesthetics (Krantzberg *et al*., 2000).

However, the presence of a contaminant is not confirmation that an adverse impact is occurring. Constituents can be naturally occurring or they can be in chemical forms that are not harmful to

biological organisms (NYSDEC, 1993). Sediment standards are quite often based solely on a review of database correlations and compilations of different field studies. Because there is such an infinite variability of organisms, sediment characteristics and combinations of constituents, science has not definitely identified sediment quality benchmarks that are totally reliable in predicting environmental harm. It is for that reason that USEPA (1994) notes that sediment quality benchmarks should not be used as mandatory clean-up levels, but instead used as a means of identifying potential areas of concern and focusing future investigations. NYSDEC (1993) notes that sediment quality criteria are used to identify areas of sediment contamination, which then should be subject to site-specific evaluation measures to quantify the levels of risk, establish remediation goals, and determine appropriate risk management actions.

As the first step in evaluating the potential harm posed by the constituents of concern that were identified in the Gowanus Canal and Gowanus Bay, the analytical data developed during the USACE sampling program was screened against salt water sediment quality criteria presented in NYSDEC (1993) and other available benchmarks. NYSDEC (1993) presents two sets of sediment screening values, one set for non-polar organic compounds and one set for metals. The non-polar compound values are based on equilibrium partitioning calculations and are presented as protective criteria for a number of different endpoints. It is noted that the identification of an appropriate screening benchmark for non-polar organic compounds under the NYSDEC protocols requires the use of a site-specific organic carbon concentration. It was not possible to use the NYSDEC non-polar organic compound screening criteria because the sediment samples were not analyzed for total organic carbon. As such, other available benchmarks from various regulatory sources were used.

Inorganic screening criteria are based on either Long and Morgan (1990) or Persaud *et al.* (1993). The Lowest Effect Level (LEL) value was used for this screening evaluation. If NYSDEC screening criteria were not available for a constituent, then other sources of screening criteria were searched for applicable values.

Table 4-1 presents the results of the comparison of the sampling results to the identified screening benchmarks. Table 4-2 lists a sample by sample summary of those constituents that exceeded their respective benchmark (or for which there was not benchmark available).

In general, the number of constituents that exceeded their respective screening criteria increased the further upstream the samples were collected. However, there were some upstream locations (CG-03-17 and CG-03-22) that had relatively few exceedances. In the majority of the downstream locations, inorganic constituents dominated the exceedances. For example, CG-03-01 had eleven constituents that exceeded benchmarks (or for which benchmarks were not available). Of those constituents, ten were inorganic constituents.

In the mid-channel section of the Gowanus Canal, the exceedances were dominated by PAHs. For example, CG-03-26 had 29 screening criteria exceedances. Of those, thirteen were PAHs, six were inorganic constituents, and seven were VOCs. At the downstream end of the Gowanus Canal (CG-03-30), the exceedances were equally distributed between the various classes of analytes.

4.2 COMPARISON OF SAMPLING RESULTS TO REGIONAL BACKGROUND CONCENTRATIONS

The New York metropolitan region is one of the largest manufacturing and industrial areas in the United States. By the mid-1800's, industries in the region included operational chemical companies, metal refining, shipbuilding, textiles, leather and tanneries. Industries considered to have the greatest environmental impact on the Gowanus Canal included MGP facilities, petroleum bulk-storage (PBS) facilities, chemical manufacturers, metal smelters, and coal yards.

All of these industries contribute an extensive load of inorganic and organic continuation into the waterbodies of the New York Harbor estuary. This load is further exacerbated by the extensive ship and barge traffic used to move chemicals and oil throughout the harbor system. Gunster *et al*. (1993) estimate that between 1982 and 1991 a total of 1,453 accidental incidents released more than 18 million gallons of hazardous materials and petroleum products in western sections

of New York Harbor. In a restricted waterbody with limited water movement, such as the Gowanus Canal, such releases would simply accumulate in layers on the sediment.

For this reason, it is important to compare the sediment sampling data from the Gowanus Canal and Gowanus Bay to ambient background as a means of further understanding the nature of the constituents that were identified there. The primary rationale behind this is a risk management approach that suggests that any potential remedial action or restoration should be focused on concentrations that are reflective of the normal background within the New York Harbor. Sediment screening values are reflective of an absolute interpretation of contamination. However, in instances where the surrounding area is already contaminated, any focused remediation or restoration without understanding what background conditions are could result in an excessive expenditure of funds and eventual recontamination from surrounding areas.

As noted in Section 2.4, a variety of sources were researched to develop an understanding of background sediment conditions throughout the New York Harbor. If the constituents that were screened in Section 4.1 exceeded their sediment quality screening criteria, they were then compared to their relative background concentrations. Table 4-3 presents a comparison of the USACE sediment data to the *average* background concentration calculated based on a review of all historic data that was identified for this step. Table 4-4 summarizes the constituents that exceeded both their sediment benchmark value and their average background value. Table 4-5 presents a comparison of the USACE sediment data to the *maximum* background concentration calculated that was identified in the historic data. Table 4-6 summarizes the constituents that exceeded both their sediment benchmark value and their maximum background value.

An examination of Table 4-3 reinforces the conclusion that the restricted nature of water movement within the Gowanus has resulted in an accumulation of constituents. The samples that were collected within the Gowanus Bay generally have low numbers of constituents that exceed both sediment screening benchmark values and average background numbers. The majority of those constituents are metals. Even within the bay, there are areas that have a number of organic constituents that exceed both sediment quality benchmarks and average background values (CG-03-07 and CG-03-09), or that have constituents for which there is no

background or benchmark. However, the Canal samples show a progressively larger number of constituents that exceed both sediment quality benchmarks and the average background numbers.

5.0 BACTERIOLOGICAL RESULTS

As part of the sediment sampling program, the USACE conducted bacteriological analysis on 25 of the collected samples. As summarized in USACE (2003), bacteria that were identified in the samples included: *Aeromonas caviae, Aeromonas salmonicida, Ahewanella putrefaciens, Bacillus cereus, Bacillus circulans, Bacillus lichenfornis, Bacillus lentimorbus, Bacillus marinus, Bacillus megaterium, Bacillus megaterium/pumulus, Bacillus mycoides, Bacillus psychrophilus, Bacillus pumilis, Bacillus sphaericus, Bacillus thuringiensis, Brevibacillus agri, Coryneform, Escherichia coli, Hafnia* and *Bacillus* species, *Brevibacillus* species, *Cellulomonas* species, *Citrobacter* species, *Enterococcus* species, *Kocuria* species, *Microbacterium* species, *Micrococcus* species, *Moraxella* species, *Paenibacillus*, *Pseudomonas* species, *Shewanella* species, *Staphylococcus* species, and *Vibrio* species. Table 5-1 lists all bacteria identified by USACE (2003), while Table 5-2 lists the concentrations of the respective samples on a colony forming unit per gram basis.

The bacteria that were identified in the sampling include bacterial specimens that are commonly found in the environment and do not have any affect on humans and those that can be infectious upon coming in contact with humans. Several of the species are commonly found in human gastrointestinal tracts and are components of human waste and sewage. Bacteria from the genus *Escherichia, Vibrio*, and *Pseudomonas* are noted as being fecal contaminants (NJDEP, 1990).

Of the more common bacteria found in the sampling, bacteria in the *Aeromonas* genus are considered to be wide spread in nature and occur in both salt and fresh water (David and Stirling, 1993, and Gold and Salit, 1993). Those species of bacteria found in the genus *Bacillus* are typically found in soil and in dust. Some of the species are known to cause food poisoning, while others are known to be involved with nitrogen cycling in organic material (Kenneth Todar University of Wisconsin-Madison, 2003). *Escherichia* and *Citrobacter* are in a group of bacteria known as the coliform bacteria that are found in the intestinal tract of humans (Guentzel, 2004). *Paenibacillus* is a non-pathogenic bacterium that is contained within waste effluents (Fannan, 2004).

The distribution of bacteria in the USACE sediment samples was fairly uniform. The number of species detected in each sample was fairly similar between the samples, though the overall concentrations appeared vary randomly between sampling stations.

There is relatively little information that can be used to evaluate the potentially ecological impacts associated with the presence of concentrations of various bacteria in sediment. There are no published sediment benchmarks and little information regarding the background concentrations of bacteria in regional sediments. A lot more emphasis has been placed, in a regulatory context, on bacterial concentrations in surface waters as they relate to human health then bacterial concentrations in sediments as they relate to ecological health. It is noted that the USACE, as per the sampling and feasibility study, is noted responsible for further evaluating health issues related to the presence of these bacteria.

6.0 SUMMARY EVALUATION AND CONCLUSIONS

As outlined in Section 2.0, the final step at evaluating the data collected by the USACE from the Gowanus Canal and Gowanus Bay was the development of a relative numeric score attributed to the general hazard posed by each of the sampling locations. Values for each constituent at each location were also developed.

At each sampling location, for organic compounds and inorganic constituents that exceeded both their respective sediment screening value and their regional background, a numerical rating between 1 and 5 (one being best, five being worst) was assigned in each of the categories of toxicity, bioaccumulation potential, persistence, and bioavailability. The rating was assigned based on professional judgment following a review of the literature regarding the chemical makeup of each analyte. Then, at each sampling location, the numerical ratings of the organic compounds and inorganic constituents that exceeded their benchmark and their background value (or for which there was no benchmark or background) were summed to get a total hazard rating. A sample specific weighting factor based on the level of benchmark exceedance was applied to the sum. The weighting factor increased with the margin by which the benchmark was exceeded, so that a constituent that slightly exceeded the benchmark was not treated the same as the constituents that significantly exceeded the benchmark.

This approach is an arbitrary approach that was implemented based on logic and professional judgment. The objective was simply to rank the sampling locations in such a manner that decisions regarding further investigation, risk management decisions, and/or remedial actions could be made in a logical progression, from those areas that required immediate attention to those areas that were consistent with the surrounding New York Harbor area.

Table 6-1 presents the values that were utilized for each chemical in each category in the development of the total hazard score. The resulting total scores for individual sample locations are presented in Table 6-2. Appendix C presents the hazard score calculation for each individual sampling location (Tables C-1 through C-25).

The results of the hazard ranking confirmed the trends observed in the other data evaluation steps. That is the hazard values increase from downstream to upstream with the samples in the Gowanus Bay having the lowest values and the highest hazard values being located upstream in the Gowanus Canal. As in the evaluation of the individual constituent classes, the highest value was actually in the mid-section of the canal at sample location CG-03-18, the next highest location was just upstream of that at location CG-03-21. This again substantiates the premise that the flushing tunnel is responsible for improving sediment in the extreme upper segment of the Canal. The hazard scores were driven by a large number of PAHs that were present at very high concentrations.

In conclusion, the USACE sediment sampling characterized the sediments in the Gowanus Bay and Gowanus canal as ranging from fair and consistent with the general health of New York Harbor sediments (in Gowanus Bay) to very poor (upper reaches of the Gowanus Canal). The extreme upper end of the Canal has seen improvement in sediment quality as a result of the actions of the flushing tunnel. This information should be used to focus future sediment delineation or benthic habitat characterization or approaches to restoration and remediation.

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Figures

Tables

Appendix A

Distribution of Individual Constituents at Individual Sampling Locations

Appendix B

Detailed Comparison of Individual Constituents at Individual Sampling Locations

Appendix C

Hazard Score Calculations for Individual Sampling Locations